Nanorovers and Subsurface Explorers for Mars.

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Abstract: Recent advances in microtechnology and mobile robotics has made it feasible to create extremely small automated or remote-controlled vehicles, which open new application frontiers. One of these possible applications is the use of nanorovers (robotic vehicles with a mass of order 1 Kg or less) in planetary exploration. NASA and Japan's Institute of Space and Astronautical Science (ISAS) are cooperating on the first mission to collect samples from the surface of an asteroid and return them to Earth for in-depth study. The ISAS MUSES-C mission will be launched on a Japanese launch vehicle in July 2002 from Japan toward a rendezvous with the asteroid 1989ML in September 2003. A NASA-provided nanorover will conduct in-situ measurements on the surface. With a mass of about 1kg, the rover experiment will be a direct descendant of the technology used to build the Sojourner rover. The rover will carry three science instruments: a visible imaging camera, a near-infrared point spectrometer and an alpha X-ray spectrometer. The solar-powered rover will move around the surface of 1989ML collecting imagery data, which are complimentary to the spacecraft investigation. The imaging system will be capable of making surface texture, composition, and morphology measurements at resolutions better than 1 mm. The rover will transmit this data to the spacecraft for relay back to Earth. Due to the microgravity environment on 1989ML, the rover has been designed to right itself in case it flips over. Solar panels on four sides of the rover will ensure that enough power will always be available to the rover to activate the motors needed to turn over. Posable struts will allow the rover to position its chassis such that the camera can be pointed straight down at the surface or straight up at the sky. The rover has been designed with the capability to right itself if it flips onto its back. Since the four posable struts are independent, the rover can be commanded to point itself in any orientation. A pointable mirror and actuated focus mechanism allow the rover to take panoramic images as well as microscopic ones. The primary rover science objectives are to carry out scientific measurements with its entire instrument suite and to transmit the data before asteroid "night," at which time, the rover will shut down until sunrise. There is little non-volatile storage on the rover. Most data not transmitted to the orbiter at the end of the daily investigation schedule will be lost. Daily investigations include visual imaging of the terrain and targets of interest, point spectra in the infrared, AXS spectra, and soil mechanics investigations using the rover as an instrument. The rover consists of a rectangular body, which is 14x14x6 cm in dimension with four wheels on four posable struts for mobility. The wheels are 6.5 cm in diameter, mounted on struts, which extend in pairs from hubs emerging from the geometric center of two opposing 14x6 cm faces of the body. Each strut is 7 cm long from the center of their pivot to the center of the wheel axis. Four of six faces of the rover body have solar cells for power generation. The top face also has the antenna element needed to transmit the radio signal. The rover can communicate as long as it is powered, with a line-of sight range of about 20 km. The rover has optical detectors on all six orthogonal exterior faces of the rover. Using these detectors, the rover will be able to determine the direction to the sun. Vertical sensing is not possible due to the unavailability of accelerometers, which can measure the micro-gravity fields of asteroids and yet fit within the mass constraints of the rover. The rover has a laser range finder, which enables it to determine the range to nearby objects. This serves a similar function to the mast-mounted stereo lander cameras used in conjunction with the Sojourner rover to localize the 3-D positions of science and engineering targets, hazards, and other objects. The rover carries three science instruments, the visual camera, the near infrared spectrometer and the alpha X-ray spectrometer. There is view window on the front face for the camera and IR spectrometer. The AXS sensor

will open out to the rear of the rover and be placed in contact with rock or regolith by appropriate body/strut motion. The entire rover system is being qualified for the temperature range of-180C to +110C, which is derived from the worst case situations during the mission. The mechanical environment for the rover is dominated by the vibration environment imposed by the ISAS MV launch vehicle. The MV is an "all solid" design and, as such, provides a relatively "rough ride". To be conservative, the mechanical elements of the rover are being designed to 100Gs and the OMRE to 125Gs. The entire rover is also being designed to be compatible with a radiation dose of about 25krad, although many components will tolerate much higher levels. Application of the nanorover to Mars is straightforward: indeed the research program under which the basic technology of the nanorover was created had Mars as the original target. Although the solar power density is less on Mars than on the MUSES-C mission target, the lower operating temperature of the solar panel should cause the amount of power available on Mars to be comparable or greater than that on the asteroid. The only hardware modification needed for Mars is the inclusion of brakes on the mobility actuators so that the vehicle can "park" without rolling or changing pose. Fortunately, accommodations for these brakes are already included in the nanorover design. Another small robotic vehicle, the Subsurface Explorer (SSX), is being developed at the Jet Propulsion Laboratory which is suitable for exploration of the deep underground environments on Mars. The device is a self-contained piledriver which uses a novel "spinning hammer" technology to convert a small continuous power feed from the surface over a two-wire tether into a large rotational energy of a spinning mass. The rotational energy is converted to translational energy by a novel mechanism described here. The hammer blows propagate as shock waves through a nosepiece, pulverizing the medium ahead of the SSX. A small portion of the pulverized medium is returned to the surface through a hole liner extending behind the SSX. This tube is "cast in place" from two chemical feedstocks which come down from the surface through passages in the hole liner and which are reacted together to produce new material with which to produce the hole liner. The lined hole does not need to be the full diameter of the SSX: approximately 100 kilograms of liner material can create a tunnel liner with a 3 mm inside diameter and a 6 mm outside diameter with at total length of 4 km. Thus it is expected that core samples representing an overlapping set of 3-mm diameter cores extending the entire length of the SSX traverse could be returned to the surface. A pneumatic prototype has been built which penetrated easily to the bottom of an 8 meter vertical test facility. An electric prototype is now under construction. It is expected that the SSX will be able to penetrate through sand or mixed regolith, ice, permafrost, or solid rock, such as basalt. It is expected that an SSX approximately 1 meter long, 3-4 cm in diameter, and with a power budget of approximately 200 Watts will be able to explore up to ~5 kilometers deep at the rate of about 10 meters per day. A preliminary subsurface exploration mission could be conducted as early as 2005, with penetration of hundreds of meters to characterize the local gradients of temperature and redox potential and perhaps locate the top of the cryosphere, for example.